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INQUIRY INTO THE INSECTICIDAL ACTION OF SOME MINERAL AND OTHER COMPOUNDS ON CATERPILLARS

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The following paper gives the detailed results obtained in a large series of tests of poisons on caterpillars. These tests were made in the hope of finding a substitute for Arsenicals. When Lead Chromate was discovered the work was stopped as the practical result had been attained, but it is desirable to publish the detailed results as a contribution to the study of insecticides. Some of the various compounds found to have definite poisoning or deterrent action may be of value outside India though they are of no value here and the detailed results are on a large enough scale to be reliable. This work was done several years ago and its publication has been delayed by the pressure on both of us of other work.

The 21st October 1912.

H. M. L.
R. S. F.

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THE use of poisons for the destruction of insect-pests has become almost universal in modern agriculture where skilled labour is employed and where the value of the crops is sufficient to warrant a considerable expenditure in the prevention of loss from this cause. Though vegetable poisons were, perhaps, the earliest in use, as the *akh* plant or the *nim* in India, modern entomology has developed the use of virulent poisons, which can be applied in very small quantity and yet be sufficient to render growing plants poisonous to many classes of pests. Arsenic is the only poison now employed on a large scale to poison the food of insects, and its various compounds have been in constant use for over half a century. Compounds of arsenic all have one disadvantage, in that careless application renders the crops poisonous not only to insects but to cattle. The careful application of standard arsenical washes to a fodder crop, for instance, will give it immunity to many insect-pests such as leaf-eating caterpillars, grasshoppers, etc., but should the strength of the standard wash be exceeded, cattle to whom it is fed will show signs of arsenical poisoning. In the United States this does not appear to be a disadvantage, any crop that is sprayed being fenced from stray cattle that would be likely to feed in such a crop, but it has been recognised that the poisonous nature of the arsenic is

an almost insuperable objection to its general use in Indian Agriculture.

The use of arsenic as an insecticide appears to have been suggested originally by its poisonous action on human beings. The digestive processes of insects are of a different nature and it is reasonable to suppose that there may be compounds which are poisonous to plant-eating insects and innocuous to cattle and man. The use of borax as a cockroach poison is a case in point where an insect can be destroyed by a substance which is far less harmful to man and domestic animals.

The following pages give an account of the experiments made to determine how far other substances than arsenic were poisonous to plant-feeding insects. The basis of the enquiry was a slender one, as there was little to show what class of compound would be likely to be effective. Apart from theoretical considerations, a substance to be a practical success must be (1) readily obtainable, (2) unaffected by rain and atmospheric influences to a considerable extent, (3) cheap, (4) without effect on plants, (5) effective at weak strengths.

Substances soluble in water would be washed off by rain and would be liable to injuriously affect plant tissues; Copper sulphate is a substance distasteful to insects, but it is soluble in water and exerts a considerable poisonous influence on living plant tissues. Lime on the other hand is insoluble in water, resists atmospheric influences, but is ineffective unless applied very densely to plants. One of the advantages of arsenic is its virulent action. A plant sprayed with water containing as little as one part by weight of lead arseniate in one thousand is poisonous to many insects; at a strength of 1 in 500 (1 lb. in 50 gallons of water), the fluid is the standard spraying mixture and renders plants poisonous to all plant-eating insects. Paris green (Copper Aceto-Arsenite) is still more virulent and can be used in smaller quantities. Evidently then it would be an advantage to have a compound that is very insoluble in water, that is unaffected by the atmosphere, that will not injure the plant, and that will be effective when applied in small quantities. The choice of compounds to test was no easy matter; omitting arsenic

compounds, the compounds of boron are alone indicated among mineral compounds, unless we include such poisons as antimony, mercury, lead, which affect man. Borax and allied compounds were worth testing on the analogy of the cockroach poisoning, and were included on that account. Other known insect poisons, used mainly as contact poisons, did not seem worth testing as their action is known. These include (1) soaps, (2) petroleum and mineral oil, (3) alkaloids of tobacco and other plants, (4) such compounds as phenol in the form of carbolic acid, sanitary fluid, creosote oil, etc., (5) rosin, (6) sulphur. The last is a known specific for special pests such as red spider, but does not appear to act as a stomach poison to insects at the strength usually applied; it was however included. With these considerations in view, a selection of insoluble compounds was made, which were tested with a number of compounds of boron. The substances selected were such as were readily obtainable or which were worth preparing for some special reason. The original aim was to investigate the comparative effect on insects of these compounds with a view to eliciting any general facts that might aid in the later selection of suitable compounds for final and exhaustive trial, working from these to a compound that would be a practical possibility on a large scale in the field.

Preliminary.—A set of tests were made on larvæ of *Caradrina exigua* feeding upon lucerne. Approximately equal quantities of the powdered substance were taken, by volume, and placed in wide-mouthed glass stoppered bottles with equal volumes of water (65. c.c.). The food was placed in the shaken up liquid, the bottle shaken up and the leaf removed and dried. All were given as much to eat as they required and were kept under the same conditions as normal larvæ which were reared upon unpoisoned food. The leaf was found not to be easily wetted so it was just dipped in alcohol and then into water to break the surface film; the leaf was then easily wetted in the poisoned water. The following compounds were thus tested for one week, and as a result of the test those in italics were omitted from further tests as being unsuitable. Borax, Copper Sulphide, *Magnesium Carbonate*, Boracic Acid, Zinc Oxide, Antimony

Sulphide, *Iron Sulphide, Manganese Dioxide, Barium Carbonate, Magnesium Oxide*, Lead Carbonate, Lead Sulphide, Lead Peroxide (Red Lead), Barium Borate; Copper Borate, Lead Borate and Barium Oxalate, were afterwards added. The basis of selection of these substances excepting in the case of Borax and Boric Acid was the property of forming insoluble compounds with Phosphoric Acid which is said to be present in large quantities in the alimentary canal of caterpillars generally. It was thought that if this is the case, the alimentary process might be interfered with to such an extent as to incapacitate the caterpillars for further damage, by administering with its food, sufficient amounts of bodies which form insoluble compounds with phosphoric acid. As a result of these tests, an attempt was made to secure greater accuracy. It was found, for instance, that young larvæ were poisoned more rapidly than slightly older ones; also that larvæ nearly full grown were apt to pupate before their time, apparently under the influence of slight poisoning or because they objected to the food given. Larvæ more nearly of an age and not near to pupation were then used. It was decided that it was useless attempting to give known amounts of food and more accurate to give as much food as they could eat.

The chief way in which accuracy could be obtained was by using as far as possible chemically equivalent amounts of each compound. Some additional compounds were added as stated above, *viz.*, Barium Oxalate, Lead Borate and Copper Borate.

The amounts used are weighed in H. equivalents of Arsenic in Lead Arseniate ($Pb_3(AsO_4)_2$), taking 1 gramme of Lead Arseniate in 100 c.c. of water as standard.

The weights actually used are, per 300 c.c. of water :—

Lead Arseniate	..	(÷ 10) 89·87	formula assumed ($Pb_3(AsO_4)_2$)	3	gr. per 300 c.c.
Lead Carbonate	..	(÷ 2) 133·45	$PbCO_3$	4·44	" " "
Lead Sulphide	..	(÷ 2) 119·5	PbS	3·96	" " "
Red Lead	..	(÷ 6) 114·1	Pb_3O_4	3·7	" " "
Barium Borate (?)	..	(÷ 12) 24	BaB_4O_7 (?)	0·8	" " "
Boracic Acid	..	(÷ 3) 21	$B(OH)_3$	0·7	" " "
Borax Aq. (10)	..	(÷ 12) 32	$Na_2B_4O_7 10H_2O$	1·0	" " "
Copper Sulphide	..	(÷ 2) 47·83	CuS	1·6	" " "

Zinc Oxide ..	(÷ 2) 40·7	ZnO.	1·3	gr. per 300 c.c.
Antimony Sulphide ..	(÷ 6) 56	Sb_2S_3	1·8	" " "
Copper Borate (?) ..	(÷12) 18	CuB_4O_7 (?)	0·60	" " "
Lead Borate (?) ..	(÷12) 30	PbB_4O_7 (?)	1·00	" " "
Barium Oxalate ..	(÷ 2) 122	BaC_2O_4	4·1	" " "

1 gr. per 100 c.c. is equivalent to 1 lb. of Lead Arseniate in 10 gallons of water, which is quite 5 times as strong as the standard wash and is three times as strong as the strongest wash ever used.

Estimation of poisoning effect.—The larvæ used were kept in boxes or open dishes, fed with fresh food dipped in the poisoned liquid. Every precaution was taken to ensure an uniform distribution of the poison in the liquid and of the liquid over the leaf. The leaf was then dried and sufficient given to the caterpillars. The amount actually given was so arranged that the larvæ would eat at least fifty per cent. of the food; when too much was given the larvæ could pick out leaves not so much poisoned but by causing them to consume nearly all the leaf, the absorption of approximately equivalent quantities of poison was ensured. The larvæ were fed twice daily and were under observation at intervals throughout the day. As each died the time was noted on the cage slip. A sample cage slip runs as follows:—

Copper Borate. 1·5 gms. (per 300 c.c.) *C. Exigua.*

		No.	Time.	Multiple.	Average.
20 *caterpillars put in 6 p.m.* ..	21. V.				
1 died 4 P.M. ..	22. V.	1	22	22	
4 died in night of ..	22. V.	4	30	120	
(3 parasitised removed).					
2 died in night of ..	23. V.	2	54	108	
2 died 10 A.M. ..	24. V.	2	66	132	
2 died 2 P.M. ..	24. V.	2	70	140	
4 died 5 P.M. ..	24. V.	4	71	284	
1 died in night ..	24. V.	1	80	80	
(1 parasitised ..	25. V.)				
		16		886	56
15 *put in 7 a.m.* ..	25. V.				
2 died in night of ..	26. V.	2	41	82	
2 died in noon ..	27. V.	2	53	106	
1 died 5 P.M. ..	27. V.	1	58	58	
4 died in night of ..	27. V.	4	65	260	
4 died at 5 P.M. ..	28. V.	4	82	328	
2 died in night ..	28. V.	2	89	178	
		15		1012	67

		No.	Time.	Multiple.	Average.
10 *put in 8 a.m.*	1. VI.				
1 died at noon	1. VI.	1	4	4	
7 died in night of	1. VI.	7	16	112	
1 died in night of	2. VI.	1	40	40	
(1 parasitised).					
3 died at noon	5. VI.	3	100	300	
		12		456	38

To compare these, the hours from time of being put in to time of death are put down on the right hand column. These figures are then averaged up and the average taken as the poisoning value of that compound at that strength and on that insect. The average in this case is 54 and the results shortly stated are that the poisoning period (Lethal Figure) of Copper Borate at ·5% on Caradrina exigua is 54 hours. The larger this figure the slower or less effective the poison. The figures for the compounds tested are tabulated below:—

TABLE I.

Name.	Amount %.	Lethal Figure.	Number of caterpillars.
Copper Borate	·5	48	53
	·2	50	50
	1·23	40	73
Copper Sulphide	·53	48	55
Antimony Sulphide	·6	23	80
Red Lead	1·23	41	50
Lead Sulphide	1·3	40	58
Zinc Oxide	·43	45	42
Lead Carbonate	1·46	78	12
Barium Oxalate	1·36	none	..
Borax	·33	none	..
,, ...	1·03	41	18
Borax and Lac.	1·03 / 5·1.5	45	17
Boric Acid	·23	none	
,, ,, ...	·7	67	20
,, ,, and Lac.	·7 / 3·5	50	38
Barium Borate	·2	none	..
,, ,, ...	1·8	54	9
Lead Borate	·33	76	16

In the next table, the maximum, minimum and lethal figures are given for each compound for each kind of larva experimented with. The lethal figure is given as a fraction the numerator of which represents the average duration of life in hours and the denominator the number of larvæ killed in that time.

TABLE II.

Name.	Amount. %	Lethal figure. Minimum.	Mean.	Maximum.	Larva.
Copper Borate ..	·5	15 4	48 53	84 4	C. exigua.
	·5	7 1	36 12	54 3	P. littoralis.
	·5	20 3	44 13	78 1	A. plexippus
	·2	21 3	50 50	84 2	C. exigua.
	·2	15 2	42 7	66 2	A. plexippus.
	·2	18 2	62 10	90 2	P. littoralis.
	1·23	6 5	40 73	66 4	C. exigua.
	1·23	6 6	18 16	63 4	A. plexippus.
Copper Sulphide ..	·53	27 6	48 55	69 4	C. exigua.
	·53	16 1	38/5	52 1	P. littoralis.
	·53	18 2	49/6	78 1	A. plexippus.
Antimony Sulphide ..	·6	6 5	23 80	67 3	C. exigua.
	·6	7 5	19 23	54 2	A. plexippus.
Red Lead	1·23	7 4	41 50	66 6	C. exigua.
	1·23	24 3	36 13	57 1	A. plexippus.
	1·23	16 1	44 9	76 1	P. littoralis.
Lead Sulphide	1·3	9 9	40 58	125 2	C. exigua.
	1·3	16 2	40 10	60 2	A. plexippus.
Barium Oxalate ..	1·36	abandoned as without effect.			
Lead Carbonate ..	1·46	..	78 12	..	....
Zinc Oxide	·43	8 4	45 42	97 3	C. exigua.
,, ,, ...	·43	no effect	(6 used)		A. plexippus.
Borax	·33	no effect.	..	..	C. exigua.
	1·03	12 2	41 18	111 1	,,
	1·03	19 2	36 9	79 1	P. littoralis.
	1·03	43 2	52 8	63 2	A. plexippus.
Borax and Lac ..	{1·03 / 5·16}	5 4	45 17	120 4	C. exigua.
(Soap)	5·16	30 1	42 11	72/1	A. plexippus. (starvation).
Boracic Acid	·23	no effect.			C. exigua.
	·7	15 1	67 20	92 3	C. exigua.
	·7	30 6	35 8	54 1	P. littoralis.
Boracic Acid and Lac ..	{·7 / 3·5}	24 2	50/38	75 4	C. exigua.
,, ,, ...	,,	died of starvation.			A. plexippus.
Barium Borate ..	0·2	no result.			
	1·8	36/1	54 9	62 4	C. exigua.
Lead Borate	·33	54 4	76 16	96 4	C. exigua.

These figures are on the whole apparently valuable; there is a general concordance between successive batches of the same species treated similarly; the average figure produced is a useful index and the high poisoning figure of antimony (23) really represents a very great mortality of the larvæ about that time. In the case of *Anosia plexippus*, a very marked disinclination to eat the leaf in some cases led to starvation and poisoning cannot be said to have occurred. As a result of these experiments, certain conclusions were arrived at; borates do not exert a marked poisoning effect; copper borate would appear to be poisonous as a copper salt not as a borate.

Of the Lead compounds, Lead Sulphide and Red Lead are equivalent, Lead Borate and Carbonate inferior. Barium compounds are apparently innocuous.

As a check, larvæ of *Sylepta* were fed in exactly the same way on untreated food and on food dipped in spirit and water.

The following are the results :—

No treatment.

20 caterpillars put in on 11th September.

17 ,, alive on 19th ,,

16 moths came out on between 25th September and 2nd October.

One pupa was killed in handling.

Fed with leaves dipped in spirit and water.

14 put in 12th September

11 alive 18th ,,

11 moths out between 25th September and 30th September. The preliminary treatment of the leaves with spirit, therefore, had no effect on the larvæ.

These results being indecisive, a larger range of compounds was chosen to elucidate if possible any general poisoning effects on caterpillars. The following Table (III) illustrates the results obtained with a varied assortment of substances all of which failed :—

TABLE III.

Substance.	Amount in 300 c.c. liquid.	Result.	Subject.
Acetamide	2·0	1 died in 30. 2 ,, ,, 48. 6 ,, ,, 60. 10 were left.	Caradrina.
Metaphenylene diamine hydrochloride ..	2·4	3 died in 30. 2 ,, ,, 54. 2 ,, ,, 60. 11 were left.	Caradrina.
Phenyl hydrazine hydro-chloride ..	1·8	2 died in 30. 6 ,, ,, 60. 12 were left.	Caradrina.
Potassium chloride	2·5	3 died in 24. 4 ,, ,, 30. 4 ,, ,, 54. 2 were parasitised. 7 were left.	Caradrina.

TABLE III—*contd.*

Substance.	Amount in 300 c.c. liquid.	Result.	Subject.
Sodium Carbonate	1·1	4 died in 30. 4 ,, ,, 54. 6 ,, ,, 60. 5 were left.	Caradrina.
Stannous Chloride	3·1	3 died in 30. 2 ,, ,, 54. 12 were left.	Caradrina.
Potassium Ferrocyanide	2·0	1 died in 24. 3 ,, ,, 36. 6 ,, ,, 60. 9 were left.	Caradrina.
Potassium Ferricyanide	1·8	2 died in 36. 5 ,, ,, 60. 12 were left.	Caradrina.
Magnesium Sulphate	1·1	1 died in 5. 4 ,, ,, 36. 1 was parasitised. 2 died in 54. 4 ,, ,, 60. 7 left.	Caradrina.
Picric Acid	2·5	1 died in 24. 3 ,, ,, 36. 5 ,, ,, 60. 10 were left.	Caradrina.
Potassium Bichromate	1·6	3 died in 36. 2 parasitised. 5 died in 60. 10 were left.	Caradrina.
Morphine	0·3	9 died in 84. 10 were left.	Caradrina.
Ammonium Persulphate	1·0	13 died in 13. 3 ,, ,, 24. 2 ,, ,, 36. 4 ,, ,, 52. 1 ,, ,, 100.	Caradrina. Average 23·20.
Ammonium Persulphate	1·0	1 died in 6. 2 ,, ,, 36. 7 ,, ,, 60. 9 were left.	Caradrina.
Ammonium Persulphate	1·0	1 died in 6. 6 ,, ,, 36. 5 ,, ,, 60. 1 ,, ,, 72. 2 ,, ,, 84.	Sylepta. Average 51·15.
Barium Peroxide	2·8	No effect.	Caradrina.
Sodium Benzoate	4·8	No effect.	Caradrina. Pierid.
Caffein	0·3	1 died in 12. 3 ,, ,, 60. 10 ,, ,, 84. 5 were left.	Caradrina.
Sodium Tartrate	3·8	1 died in 60. 1 ,, ,, 168. 18 pupated.	Pierid.
Zinc Sulphide	1·5	No effect.	Pierid. Caradrina.
Tartaric Acid	2·5	.. ..	Caradrina.
Alum	5·9	.. ..	,,

TABLE III—*concld.*

Substance.	Amount in 300 c.c. liquid.	Result.	Subject.
		Died in 3 to 7 days.	Pierid.
Chrome Alum	5·5	No effect.	,,
		,, ,,	Caradrina.
Sulphur	0·5	,, ,,	,,
		,, ,,	Pierid.
Quinine	5·0	,, ,,	Caradrina.
		,, ,,	Pierid.
Carbolic Acid	3·0	,, ,,	Caradrina.
		One died on account of contact effect, the acid producing a sore on the skin.	Pierid.
Succinic Acid	1·9	No effect.	Caradrina.
		,, ,,	Pierid.
Sodium Succinate	2·8	No effect.	Caradrina.
		,, ,,	Pierid.
Tannic Acid	3·0	,, ,,	Caradrina.
		,, ,,	Pierid.
Gallic Acid	3·4	,, ,,	Caradrina.
		,, ,,	Pierid.
Brucine	0·3	,, ,,	Caradrina.
		,, ,,	Sylepta.

In Table IV we illustrate the action on three different caterpillars of varying strengths of one compound to show the degree of variation experienced—

TABLE IV.

Substance.	Amount in 300 c.c.	Number of caterpillars.	Figure.		Species.
	Gms.				
Copper Sulphide	·5	20	36·7		Prodenia.
,, ,, ...	·5	12	64		Caradrina.
,, ,, ...	·5	18	50	58	,,
,, ,, ...	·5	14	91		Pierid.
,, ,, ...	1·5	20	35		Prodenia.
,, ,, ...	1·5	13	76		Pierid.
,, ,, ...	1·5	12	58		Caradrina.
,, ,, ...	1·5	20	42	43	,,
,, ,, ...	1·5	19	35·8		,,
,, ,, ...	4·5	20	40		Prodenia.
,, ,, ...	4·5	18	26		Caradrina.
,, ,, ...	4·5	16	23	31	,,
,, ,, ...	4·5	20	41		,,
,, ,, ...	4·5	4	24		Anosia.
,, ,, ...	4·5	19	23		Pierid.
,, ,, ...	4·5	20	27·4		,,
,, ,, ...	9·0	20	32		Prodenia.
,, ,, ...	9·0	15	21		Caradrina.
,, ,, ...	9·0	18	33	20	,,
,, ,, ...	9·0	20	23·5		,,
,, ,, ...	9·0	18	19		Pierid.
,, ,, ...	9·0	20	17·5		,,

In Table V are shown the results of a number of compounds on various caterpillars; we give only the average figure for each experiment. As far as possible not less than 20 caterpillars, of even medium size, were used, but in some cases the experiments totalled up to over 100 individuals in all—

TABLE V.

Substance.	Amount in 300 c.c. water.	LETHAL FIGURES.								
		Sylepta.	Caradrina.	Anosia.	Marasmia.	Prodenia.	Diacrisia.	Cosmophila.	Pieris.	Ophiusa.
	Gms.									
Iodoform ..	4·4	10	15	..	..	..	..	13·6	..	..
	1·5	8·5	..	..	..	..	..	..	..	..
	0·5	10·5	51	..	..	..	18·0	..	..	10·7
	0·3	18·5	51	..	..	..	12·5	..	..	20·0
	1·0	..	..	..	..	..	..	..	12	..
Arsenious Oxide ..	2·0	11·8	..	..	..	..	..	..	..	..
Mercurous Iodide ..	7·5	15·6	14	..	..	..	..	..	..	..
Cuprous Cyanide ..	2·7	..	46	..	..	..	..	..	..	..
	1·9	11·2	41	..	33	..	17·3	25·5	..	..
	0·95	10·3	..	..	41·5	..	26·5	..	..	..
Lac	4·0	18·75	..	..	..	..	13·6	..	..	..
Borax .. Lac Soap ..	3·1 15·5	..	45	..	..	..	..	..	..	..
Boric Acid .. Lac	2·1 10·5	..	50	..	..	..	..	..	..	..
Boric Acid ..	2·1	..	67	..	..	35	..	..	..	..
Borax	3·1	..	41	42 52	..	36	..	..	..	..
	1·0	..	No effect	..	..	..	..	..	..	..
Copper Borate ..	3·7	..	40	40	..	..	..	..	..	..
	1·5	..	36 52	44	..	..	..	..	..	..
	0·6	..	50	42	..	62	..	..	..	..
Barium Borate ..	5·4	..	51	..	..	..	..	..	..	..
Lead Arseniate ..	3·0	17·7	16·5	..	..	26	11·8	..	8	..
	4·5	..	..	..	..	..	..	..	12	10·3
Lead Sulphide ..	3·9	..	40·0	40	..	..	..	..	..	..
Lead Carbonate .	4·38	..	78·0	..	..	..	..	..	..	..
Red Lead ..	3·7	..	41·0	..	..	44	..	..	..	..
	4·7	..	..	36	..	..	..	..	..	..
Calcium Cyanamide	2·7	24	46	..	72·6	..	all lived.	..	..	..
Phenyl Hydrazine Hydrochloride ..	1·8	27·3	..	..	..	..	14·0	..	..	..
Mercuric Chloride ..	4·5	36·4	35	..	..	..	..	..	..	..
	1·0	36·3	..	..	..	..	18·5	..	..	..
	0·5	30·5	..	..	..	..	28·8	25·2	..	..
Antimony Sulphide	1·8	..	23	19	..	..	..	..	..	..
Copper Sulphide ..	4·5	..	30	24	..	40	..	..	27·7	..
	1·6	..	48	49	..	38	..	..	..	..
	1·5	..	45·2	..	..	35	..	..	76	..

TABLE V—*concld.*

Substance.	Amount in 300 c.c. water.	Lethal Figure.								
		Sylepta.	Caradrina.	Anosia.	Marasmia.	Prodenia.	Diacrisia.	Cosmophila.	Pierid.	Ophiusa.
	Gms.									
Copper Sulphide ..	0·5	..	57·0	..	..	36·7	..	..	91	..
Chloral Hydrate ..	2·75	..	35·8	..	..	..	..	..	..	..
Zinc Oxide ..	1·3	..	45·0	..	..	..	..	..	..	..
Strychnine ..	0·3	..	46	..	..	..	..	..	..	..
Brucine ..	0·3	..	67	..	..	..	..	..	26·5	..
Naphthaline ..	1·0	..	..	..	..	..	5	..	..	77·0
	2·0	..	..	..	..	..	..	..	..	36·1
Saccharin ..	2·0	58·7	..	..	..	..	..	..	..	..
Potassium Iodide ..	5·5	..	42	..	..	..	..	..	..	..

In Table VI are shown the same figures as in Table V, only put under each species of insect separately—

TABLE VI.

Substance.	Weight of substance in 300 c.c. water.	Caterpillars.	Average time required to kill, in hours.
	Gms.		
Iodoform	1·5	Sylepta	8·5
	4·4	,,	10·0
	0·5	,,	10·5
	0·3	,,	18·5
Arsenious Oxide	2·0	,,	11·8
Mercurous Iodide	7·5	,,	15·6
Cuprous Cyanide	1·9	,,	11·2
	0·95	,,	10·3
Lac	4·0	,,	18·75
Lead Arseniate	3·0	,,	17·7
Calcium Cyanamide	2·7	,,	24·0
Phenyl Hydrazine Hydrochloride	1·8	,,	27·3
Mercuric Chloride	0·5	,,	30·5
	4·5	,,	36·4
	1·0	,,	36·3
Saccharin	2·0	,,	58·7
Iodoform	4·4	Caradrina.	15
	0·5	,,	51
	0·3	,,	51
Mercurous Iodide	7·5	,,	14
Lead Arseniate	3·0	,,	16·5
Antimony Sulphide	1·8	,,	23·0
Copper Sulphide	4·5	,,	30·0
	1·5	,,	45·2
	1·6	,,	48·0
	0·5	,,	57
Chloral Hydrate	2·75	,,	35·8
Mercuric Chloride	4·5	,,	35·0

TABLE VI—*contd.*

Substance.	Weight of substance in 300 c.c. water.	Caterpillar.	Average time required to kill, in hours.
	Gms.		
Copper Borate	1·5	Caradrina	36·0
	3·7	..	40·0
	1·5	..	52·0
	0·6	..	50·0
Lead Sulphide	3·9	..	40·0
Red Lead	3·7	..	41·0
Borax	3·1	..	41
	1·0	..	No effect.
Cuprous Cyanide	1·9	..	41·2
	2·7	..	46·0
Borax / Lac / Soap	3·1 / 15·5	..	45·0
Boric Acid / Lac	2·1 / 10·5	..	50·0
Zinc Oxide	1·3	..	45·0
Cuprous Cyanide	2·7	..	46
Strychnine	0·3	..	46
Barium Borate	5·4	..	54
Brucine	0·3	..	67
Boric Acid	2·1	..	67
Lead Carbonate	4·38	..	78
Potassium Iodide	5·5	..	42 for 8. 16 unaffected.
Copper Sulphide	4·5	Anosia.	24
	1·6	..	49
Antimony Sulphide	1·8	..	19
Copper Borate	3·7	..	40
	0·6	..	42
	1·5	..	44
Red Lead	4·7	..	36
Lead Sulphide	3·9	..	40
Borax	3·1	..	42
	3·1	..	52
Cuprous Cyanide	1·9	Marasmia.	33
	0·95	..	41·5
	2·7	..	72·6
Borax	3·1	Prodenia.	36
Red Lead	3·7	..	44
Copper Borate	0·6	..	62
Boric Acid	2·1	..	35
Copper Sulphide	0·5	..	36·7
	4·5	..	40·0
	1·5	..	35·0
	1·6	..	38·0
Lead Arseniate	3·0	..	26·0
Copper Sulphide	0·5	Pierid.	91·0
	1·5	..	76·0
	4·5	..	27·7
Brucine	0·3	..	26·5
Lead Arseniate	3·0	..	8·0
	4·5	..	12·0
Iodoform	1·0	..	12·0
Cuprous Cyanide	1·9	Cosmophila.	25·5
Iodoform	4·4	..	13·6
Mercuric Chloride	4·5	..	25·2

TABLE VI—*concld.*

Substance.	Weight of substance in 300 c.c. water.	Caterpillars.	Average time required to kill, in hours.
	Gms.		
Phen. Hyd.	1·8	Diacrisia.	140
Lac	4·0	,,	136 (starved 3 days).
Mercuric Chloride	1·0	,,	18·5
	0·5	,,	28·8
Calcium Cyanamide	2·7	,,	all lived 8 days,
	2·0	,,	no result.
Cuprous Cyanide	0·95	,,	26·5
	1·9	,,	17·3
Lead Arseniate	1·0	,,	44·8
Iodoform	0·3	Diacrisia.	12·5
	0·5	,,	18·0
Naphthaline	1·0	,,	9·0
Lead Arseniate	4·5	Ophiusa.	40·3 leaves not eaten.
Calcium Cyanamide	2·7	,,	2 in 6 hours. 6 pupated in 5 to 13 days.
Iodoform	0·5	,,	10·7
	0·3	,,	20·0
Naphthaline	2·0	,,	36·1
	1·0	,,	77·0

The above experiments were all on caterpillars and material being available a small series were therefore done on a grasshopper (*Acridium aeruginosum*). The following are the results:—

Substance.	Amount.	No.	Time taken to kill.	Average.
	Gms.			
Copper Cyanide	·95	3	1 in 54 hours. 2 ,, 80 ,,	71
,, ,, ...	·95	3	1 ,, 36 ,, 1 ,, 72 ,, 1 ,, 96 ,,	68
Mercuric Chloride	1·0	3	2 ,, 60 ,, 1 ,, 84 ,,	68
Iodoform	1·0	5	3 ,, 44 ,, 1 ,, 92 ,, 1 ,, 126 ,,	70
,, ...	1·0	3	1 ,, 48 ,, 1 ,, 60 ,, 1 ,, 144 ,,	84
Lead Arseniate	3·0	4	2 ,, 7 ,, 2 ,, 72 ,,	37
,, ,, ...	3·0	4	2 ,, 14 ,, 1 ,, 26 ,, 1 ,, 120 ,,	18·5

Substance.	Amount.	No.	Time taken to kill.	Average.
	Gms.			
Calcium Cyanamide	2·7	4	3 in 30 hours. 1 .. 21 days.	?
Iodoform	0·5	4	1 in 7 hours. 2 .. 48 ..	34·3
"	0·5	3	2 .. 60 .. 1 .. 108 ..	76
"	0·3	4	1 .. 14 .. 1 .. 120 .. 1 .. 12 ..	?
Naphthaline	2·0	4	2 .. 80 .. 1 .. 12 .. 1 .. 16 ..	?
"	1·0	3	1 .. 168 .. 1 .. 12 .. 1 .. 19 ..	?

We class the compounds tested as follows—

Class I.—Average killing effect is under 20 hours :—

Iodoform.
Lead Arseniate.
Antimony Sulphide.
White Arsenic.
Mercuric Iodide.
Copper Cyanide.
Naphthaline.

CLASS II.—Average killing effect is from 20 to 40 hours :—

Copper Sulphide.
Strychnine.
Calcium Cyanamide.
Mercuric Chloride.
Copper Borate.
Red Lead.
Lead Sulphide.
Borax.
Boracic Acid.

CLASS III.—Average killing effect is from 40 to 100 hours :—

Lead Carbonate.
Barium Borate.

Zinc Oxide.
Lead Borate.
Lac and Borax.
Lac and Boric Acid.

The results of these experiments are not encouraging as they give us neither a definite principle nor any one compound to select. In class I are violent cattle or human poisons ; Iodoform is useless for every reason ; Antimony Sulphide is too poisonous ; White Arsenic is impossible as it is soluble and poisonous ; Mercuric Iodide is poisonous ; Copper Cyanide is poisonous ; Naphthaline is under certain circumstances extremely valuable and we deal with it further below.

Copper Sulphide might be valuable and its use is indicated. Strychnine is useless on every ground. In class II Calcium Cyanamide might have been promising had not its action on plants been too strong (see below). Mercuric Chloride is of course useless ; Copper Borate might give good results ; so might Red Lead or Lead Sulphide. Borax and Boracic Acid were abandoned after trial on plants (see below). Our attention is then directed to Naphthaline, Copper Sulphide, Copper Borate, Red Lead and Lead Sulphide.

On thinking over these experiments during the cold weather while waiting till fresh ones become possible, the Red Lead suggested the trial of commercial paints, *i.e.*, finely ground dry paints. A selection was obtained and tried. Table VII gives the results.

TABLE VII.

Diacrisia obliqua larvæ were used and all poisons at 1 lb. in 16 gallons of water (1·5 grammes per 300 c.c.)

Lemon Chrome—

3 died in 72 hours.
7 ,, ,, 96 ,,
1 ,, ,, 144 ,,
1 ,, ,, 192 ,,
Eight pupated.

There was a distinct period of two days starvation before they fed at all, so that 48 hours should be deducted from these figures.

Ultramarine Blue—No action.
Yellow Ochre ,, ,,

Prussian Blue—

1 died in 60 hours.
1 ,, ,, 72 ,,
2 ,, ,, 120 ,,
1 ,, ,, 192 ,,
15 pupated.

Burnt Umber—

6 died in 168 hours.
14 pupated.

Burnt Sienna—

1 died in 36 hours.
3 ,, ,, 44 ,,
16 pupated.

White Lead—

2 died in 192 hours.
18 pupated.

Oxide of Iron—

1 died in 96 hours.
4 ,, ,, 120 ,,
2 ,, ,, 144 ,,
13 pupated.

Of these Lemon Chrome seemed valuable and experiments on *Diacrisia obliqua* in the open gave very promising results. The caterpillars starved rather than eat plants sprayed with it at 1 lb. in 16 gallons. Accordingly this paint was analysed and found to contain 5 per cent. of Lead Chromate, with gypsum. Lead Chromate was then prepared pure and tested; Barium Chromate was also

tested to see if it was the Chromate or the Lead, and if Barium could replace the Lead. The following results were obtained :—

Barium Chromate, 1·0 gramme in 300 c.c., *i.e.*, 1 lb. in 32 gallons of water.

15 caterpillars—1 died in 18 hours, 3 more in 66, the rest pupated after 100 or more hours. The difficulty of wetting cabbage leaf was a factor of importance.

On Caradrina exigua—

10 young put in :
1 missing in 2 days.
1 ,, ,, 4 ,,
1 ,, ,, 5 ,,
1 pupated .. 5 ,,

the rest missing gradually, 1 survived, which pupated on the 13th day prematurely. The caterpillars eat each other vigorously from starvation as the poison upset them without killing them.

On Attacus ricini—

5 2nd instar worms put in 13th.
1 died on 15th.
3 ,, ,, 18th.
1 ,, ,, 29th.

Lead Chromate, 1·0 gramme in 300 c.c. or 1 lb. in 32 gallons of water :—

Pieris brassicæ—

15 caterpillars—3 died in 24 hours, 1 in 36, 1 in 96 (average 40), the rest pupated after the 4th day. The difficulty of wetting the leaves was a factor of importance.

Caradrina exigua—

10 larvæ, in 3 days only 7 left, on the 4th day 5 found dead, 1 died on the 5th day and the last on the 6th day. So long as they fed on each other, they did not touch the leaves at all. When they did, they died.

Attacus ricini—

Five 2nd stage worms: they refused to eat, only nibbling here and there; 2 died in 1 day, 3 in 2 days.

Diacrisia obliqua—

15 larvæ: they starved for 5 days—1 died on 5th day, 1 on 6th, 5 on 8th, 8 on the 10th.

15 larvæ: they starved for 5 days—1 died on 5th day, 1 on 6th, 11 on 8th, 2 on 9th.

The very marked feature of this, more marked even than with Barium Chromate is their refusal to eat it, as was also seen in the case of caterpillars in large cages where the plants were sprayed. We have seen no compound in which this aversion is quite so marked, and though we used very many Caradrina larvæ, which are fairly cannibalistic, it was only with these two compounds that the cannibalism was so extensive. It is clearly a very good deterrent and when starvation compels, a very good poison. Its general qualities are discussed below.

PART II.

It is clear that the figures obtained are not an absolute index of the poisonous effect of the various compounds particularly with some of the compounds in which the action was uncertain. In many cases, a few of the caterpillars were killed quite early while others lived for long periods; it appeared as if either the caterpillars accustomed themselves to some poisons, or they learnt to detect them, or they had a very varying degree of resistance to the poison or to starvation. In one case with borax the minimum was 12, the maximum 111. Where the maximum went over 96 hours, we rejected the compound even if the minimum was small, and of course the average figure does show the effect of the big maxima. To simplify the question and to give the results more simply, we give here the characteristic behaviour of each compound as derived from both observation of the behaviour of the caterpillars and the actual figures—

Class I.—Iodoform.
White Arsenic.
Mercuric Iodide.
Copper Cyanide.
Mercuric Chloride.
Naphthaline.
Lead Arseniate.
Antimony Sulphide.

Class II.—Calcium Cyanamide.
Lead Chromate.
Barium Chromate.
Lead Sulphide.
Lead Oxide (Red Lead).

Boracic Acid.
Borax.
Copper Sulphide.
Copper Borate.

Class III.—Lac, Borax and Soap.
Lac, Boric Acid.
Copper Tannate.
Lead Carbonate.
Barium Borate.
Zinc Oxide.
Lead Borate.

Class IV.—Barium Peroxide.
Sodium Benzoate.
Caffein.
Sodium Tartrate.
Zinc Sulphide.
Tartaric Acid.
Alum.
Chrome Alum.
Sulphur.
Quinine.
Carbolic Acid.
Succinic Acid.
Sodium Succinate.
Tannic Acid.
Gallic Acid.
Lac.
Chloral Hydrate.
Strychnine.
Brucine.
Saccharin.
Potassium Iodide.
Lemon Chrome Paint.
Ultramarine Blue Paint.

Yellow Ochre Paint.
Prussian Blue Paint.
Burnt Umber Paint.
Burnt Sienna Paint.
White Lead Paint.
Oxide of Iron Paint.
Lead Tannate.
Magnesium Carbonate.
Iron Sulphide.
Manganese Dioxide.
Barium Carbonate.
Magnesium Oxide.
Barium Oxalate.
Acetamide.
Metaphenylene Diamine Hydrochloride.
Phenyl Hydrazine Hydrochloride.
Potassium Chloride.
Sodium Carbonate.
Stannous Chloride.
Potassium Ferrocyanide.
.. Ferricyanide.
Magnesium Sulphate.
Picric Acid.
Potassium Bichromate.
Morphine.
Ammonium Persulphate.

The results are expressed as follows :—

The number of larvæ used (No. 10) : "the minimum period" is the number killed in the shortest period (minimum 3/6 means "three killed in 6 hours").

"The maximum period" is the number that died last and their period (maximum 2/30 means "two killed in 30 hours"): average is the average figure as worked out on pages 281-2.

LEAD ARSENIATE. $Pb_3(AsO_4)_2$.

Sylepta multilinealis—

3·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
10	3/6	2/30	17·9	
20	7/7	4/37	16·9	17·7
20	4/6	2/49	19·4	
20	6/6	1/49	16·6	

Caradrina exigua—

3·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	3/6	6/30	15	16·5
17	5/5	4/38	18	

Prodenia littoralis—

3·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	8/12	9/36	24	26
19	5/11	7/37	28	

Pierid—

3·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	14/6	2/12	7	8
20	10/4	10/14	9	
8	5/6	1/21	1/30	12

Diacrisia obliqua—

1·0 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
16	2/7	1/67	44·5	
10	1/42	9/54	53	44·8
20	5/7	1/79	37	

There was a marked refusal to feed at first.

Prodenia littoralis—

3·0 grammes per 300 c.c.

No. 7.—Minimum 5/30. Maximum 1/78. Average 40. Leaves not eaten at first.

Acridium aeruginosum—

3·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
4	2/7	2/72	1/120
4	2/14	1/26	

In all cases, this insect was erratic: those that fed freely died quickly.

Ophiusa melicerte—

1·0 gramme per 300 c.c.

On growing plants in the open, *sprayed*.

Minimum 6/20. Maximum 1/252. Average 85.

3·0 grammes per 300 c.c. in cage.

Minimum 5/30. Maximum 1/68. Average 37.

The leaves were very little eaten at first.

Lead Arseniate may be, in a sense, taken as a standard, and the very strongest used in practice is 1·0 gramme per 300 c.c. usually much less. But to get comparative effects we must use our compounds stronger. We would point out that on the analogy of this particularly, any of the compounds that give a figure below 80 or 100, if they can be applied at that strength, are possible insecticides for field use.

WHITE ARSENIC. As_2O_3.

Sylepta multilinealis—

2·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	14/6	2/78	18	11·8
20	15/6	5/13	7·75	
20	10/7	3/26	12·25	
20	16/6	2/31	9·2	

Comparing this with Lead Arseniate, for the same insect, one sees how consistently this is more rapid in action. It is of course inadmissible as an insecticide owing to its burning action, but it is the really effective poisoning ingredient of all arsenicals.

ANTIMONY SULPHIDE. Sb_2S_3.

Caradrina exigua—

1·8 grammes per 300 c.c.

No. 80. Minimum 5/6. Maximum 3/67. Average 23.

Anosia plexippus—

1·8 grammes per 300 c.c.

No. 23. Minimum 5/7. Maximum 2/54. Average 19.

This is a very deadly compound; the experiment with *Caradrina* alone was done on lots varying from 4 to 20 and was so consistent that the figures are combined. It is inadmissible as a practical insecticide in India.

IODOFORM. $C\,H\,I_3$.

Sylepta derogata, Fabr.—

1·5 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	17/6	3/13	7	
20	17/7	3/14	8	
20	14/7	3/14	9	8·4
20	9/6	11/13	10	
20	16/7	4/13	8	

4·4 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	16/6	4/54	11·7	
20	14/6	6/13	8·1	10
18	11/6	7/13	9·3	

0·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
19	17/6	2/13	7	
20	19/6	4/13	6·3	
20	12/6	2/62	15	
20	18/7	2/14	8	10·5
20	5/6	2/42	19·8	
25	..	25/7	7	

0·3 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	14/6	2/61	16·5	
20	11/6	2/78	29·6	18·5
23	15/7	8/14	9·5	

In all these experiments, as in later ones, the caterpillars were kept in well-ventilated cages, as the fumes of Iodoform affected them very strongly.

Caradrina exigua—

0·3 gramme per 300 c.c.

No. 20. Minimum 4/7. Maximum 3/109. Average 51.

0·5 gramme per 300 c.c.

No. 12. Minimum 2 13. Maximum 3/85. Average 51.

4·4 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	6 6	2 27	12	10·5
20	19 8	1 32	9	

Pierid—

1·0 gramme per 300 c.c.

No. 8. Minimum 5/7. Maximum 3/19. Average 11·4.

Cosmophila sabulifera—

4·4 grammes per 300 c.c.

No. 10. Minimum 2/4. Maximum 2/25. Average 13·6.

Diacrisia Obliqua—

0·3 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
28	22/6	6/18	9	12·5
10	5 6	1 42	15·6	
10	5 7	5 19	13·	

0·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
30	15 30	15 42	36	18
10	5 7	5 31	19	
11	8 6	1 38	10	
10	..	10 7	7	

Ophiusa melicerte—

0·5 gramme per 300 c.c.

No. 8. Minimum 6/8. Maximum 1/20. Average 11.

0·3 gramme per 300 c.c.

No. 6. Maximum 6/20. Average 20.

Acridium aeruginosum—

1·0 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
5	3/44	1 92	1 126
3	1/48	1 60	1 144

0·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
4	1/7	2/48	1/34
3	2/60	1/108	1/76

0·3 gramme per 300 c.c.

No. 4. Minimum 1/14. Maximum 1/20. Average 1/29·8.

Except for the last, the experiments show the very great killing effect of this compound; the grasshopper used in the last would not eat leaves tainted with it and the resistant powers of a large grasshopper, are apparently greater than those of a caterpillar; the grasshopper simply refrained from food.

Iodoform is of course useless as an insecticide; but its action is very marked and is, we believe, worth following up with similar compounds. Iodoform is moderately volatile and its action in the open is of interest.

1·0 gramme per 300 c.c. on castor plants in the open, with *Ophiusa melicerte*—

No. 10—1/34. 1/96. 1/108. 2/124. 2/160. 1/184.

The plant was much burnt by the iodoform and the caterpillars simply tried spot after spot, trying to find a place free of iodoform.

MERCURIC CHLORIDE. $Hg\,Cl_2$.

Sylepta derogata—

0·5 gramme per 300 c.c.

No. 20. Minimum 3/6. Maximum 1/73. Average 30·5.

1·0 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	1/6	3/85	52·2	
20	7/8	1/62	26·8	36·3
24	12/14	2/62	30	

4·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
15	2/6	2/108	61	
19	2/6	1/73	34·5	36·4
20	8/8	1/38	13·6	

The irregularity in action is very marked but it is due to the fact that very early the caterpillars become affected by a small

amount of food and then lie moribund for hours. Although in this case the figures put this compound low, it is a very certain poison.

Caradrina exigua—

4·5 grammes per 300 c.c.

No. 20. Minimum 2/24. Maximum 18/36. Average 35.

Cosmophila sabulifera—

4·5 grammes per 300 c.c.

No. 10. Minimum 3/7. Maximum 2/49. Average 25·2.

Diacrisia obliqua—

0·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
10	5/18	1/42	25·2	28·8
10	6/18	2/78	32·4	

1·0 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	11/6	4/30	13·8	
10	1/6	1/54	30·0	18·5
10	7/7	1/31	11·8	

Acridium aeruginosum—

1·0 gramme per 300 c.c.

No. 3. Minimum 2/60. Maximum 1/84. Average 68.

Mercuric chloride is, as would be expected, a violent poison; it is soluble, totally unsuitable as an insecticide and merely illustrates the fact that an irritant poison affects insects as other organisms.

MERCURIC IODIDE. Hg_2I_2.

Sylepta derogata—

7·5 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
17	6/6	2/78	26	
20	13/13	3/37	19	
20	6/7	2/37	15·3	15·6
20	20/8	..	8	
20	12/7	8/14	10	

Caradrina exigua—

No.	Minimum.	Maximum.	Average.	
22	1/5 14/12	1/36	16·5	14
20	20/12	..	12	

Cosmophila sabulifera—

No. 10. Minimum 2/4. Maximum 3/36. Average 21·5.

This body is evidently a first-class poison, possibly combining the action of the mercury and the iodine as it is perceptibly quicker in action. It is to be classed with the arsenicals but is not useful in practice.

COPPER CYANIDE. $Cu(C.N.)_2$.

Sylepta derogata—

0·95 gramme per 300 c.c.

No. 20. Minimum 11/6. Maximum 1/37. Average 10·3.

1·9 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
19	6/6	2/37	16·8	
20	14/6	3/25	10	
20	8/7	2/28	12·5	
19	12/6	7/13	8·6	11·2
20	20/8	..	8·0	
25	22/6	3/18	7·3	
20	16/6	2/30	9·6	
12	2/4	3/36	16·6	

Caradrina exigua—

1·9 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
14	1/13	4/61	41·2
17	3/12	8/60	41·

Cosmophila sabulifera—

1·9 grammes per 300 c.c.

No. 10. Minimum 3/13. Maximum 3/36. Average 25·5.

Diacrisia obliqua—

0·95 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	5/6	4/30	17·2	26·5
20	2/7	2/79	35·8	

1·9 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
25	22/22	3/30	23	
22	2/6	3/78	48	17·3
10	8/6	2/30	10·8	

Marasmia trapezalis—

0·95 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
21	9/44	2/86	35·3 } 41·5
16	11/31	5/85	47·8 }

1·9 grammes per 300 c.c.

No. 19. Minimum 3/6. Maximum 4/62. Average 33.

Acridium aeruginosum—

0·95 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
3	1/51	2/80	..
3	1/36	1/72	1/196

As in other cases, the grasshopper simply declines food and waits: but the effect of this compound is fairly well marked.

Copper cyanide is clearly a violent poison, and is extremely interesting as being an insoluble cyanide, whose effect one might expect to be very good. The cyanides are, unfortunately, inadmissible in practice.

Napthalin.

There are two series of experiments here; in the first, the napthalin was not properly emulsified but was finely divided in water and its distribution on the leaf uneven; in the second an emulsion was formed but as this contains kerosine, size and soft soap, the results are not wholly attributable to napthalin. In both series the figures are not individually reliable.

Sylepta derogata—

0·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
20	16/6	4/12	7·25
20	5/6	5/144	55
17	3/7	3/158	63

1·0 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
19	16/6	3/12	7·0
18	7/6	2/78	42

2·0 grammes per 300 c. c.

No.	Minimum.	Maximum.	Average.
20	20/7	.	7
20	20/7	..	7
20	16/6	4/18	8·1

In the last series especially the napthalin separates out on the leaves in crystals and the caterpillars eat these and die very soon. The figures are probably valueless.

2·0 grammes in 300 c.c. spirit.

No.	Minimum.	Maximum.	Average.
20	20/12	..	12
10	4/6	2/36	16·8

Ten lived over and pupated. at intervals of 7 to 11 days and were apparently unaffected.

2·0 grammes with 4·0 grammes lac.

No. 18. Minimum 17/6. Maximum 1/12. Average 6.

Two pupated two days after.

No.	Minimum.	Maximum.	Average.
20	20/6	..	6
12	4/54	1/192	82·5

Eight pupated in 9 to 12 days.

The above series, done with one species, show how variable the apparent action is, due to errors of experiment purely. When napthalin in solid form was applied to the leaf they died quickly, or they survived indefinitely, owing to their no longer absorbing any napthalin. It is useless to give details of the long series of experiments made with all the species: the following are extracted at random:—

Ophiusa melicerte—

1·0 gramme per 300 c.c.

No. 6. Minimum 2/48. Maximum 1/168. Average 77·0.

Caradrina exigua—

Napthalin 2·0 grammes. Lac 4·0 grammes per 300 c.c.

No. 17. Minimum 3/54. Maximum 1/160. Average 98.

Napthalin 2·0 grammes in 300 c.c. spirit.

No. 16. Minimum 12/78. Maximum 4/100. Average 94.

Pierid caterpillar—

No. 20. Minimum 1/15. Maximum 1/111. Average 63.

Acridium aeruginosum—

No.	Minimum.	Maximum.	Average.
3	1/168	1 in 12 days	1 in 19 days.
4	2/80	1 „ 12 „	1 „ 16 „

A series was done then with napthalin emulsion on *Diacrisia obliqua*—

No.	Minimum.	Maximum.	Average.
8	8/5	..	5
15	12/14	3/38	20
15	15/6	..	6
15	15/4	..	4
15	15/5	..	5

In this case the napthalin was thoroughly emulsified, the emulsion thoroughly mixed and the distribution on the leaf even. The killing effect may not be due wholly to napthalin. (*See* Appendix III.)

We here leave napthalin with the opinion that it is a first class insecticide, but as practical experience showed, too volatile to be of use except in special cases. (*See* Appendix III.)

Barium Chromate—

See remarks above on p. 286.

Lead Chromate—

See summary above on p. 286.

CALCIUM CYANAMIDE. $Ca\,CN_2$.

Sylepta derogata—

2·7 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.	
20	2/6	13/54	41·4	
20	2/6	4/37	29·7	
20	3/6	12/37	26·3	24
20	16/7	2/38	10·8	
19	8/6	2/25	11·4	

Caradrina exigua—

No. 13. Minimum 1/12. Maximum 6/60. Average 46.

Marasmia trapezalis—

No. 20. Minimum 1/6. Maximum 2/128. Average 72·6.

Ophiusa melicerte—

No. 20. Minimum 2/8, rest pupated in from 5 to 13 days.

Diacrisia obliqua—

No.	Minimum.	Maximum.	Average.
22	4/6	1/128	45·
20	2/6	13/54	41·4
20	2/6	4/37	29·7
20	3/6	12/37	26·3
20	16/7	2/38	10·8
19	8/6	2/25	11·4
20	1/6	2/128	72·6

Acridium aeruginosum—

No. 4. Minimum 3/30. Maximum 1/500.

The above were all experiments in the open; experiments were made on live plants in cages.

Ophiusa melicerte—

2·7 grammes in 300 c.c.

Two died in 6 hours, 6 lived and pupated after 5 to 13 days.

Diacrisia obliqua—

1 lb. to 12 gallons. (2½ lbs. used as the cyanamide is 40 per cent. pure). Thirty caterpillars, no results, the leaves not eaten and all turned brown. Done on castor and groundnut.

This compound seems to be effective if evenly applied, but undoubtedly burns foliage excessively. Its uneven action is probably explained by the compound, though finely ground, not being evenly distributed, the particles of the actual cyanamide not being properly diffused through the mass or in the water.

COPPER BORATE. $Cu\ B_4O_7$.

Caradrina exiqua—

·6 gramme per 300 c.c.

No. 50. Minimum 3/21. Maximum 2/84. Average 50.

1·5 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
41	4/15	4/84	52
12	1/7	3/54	36

3·7 grammes per 300 c.c.

No. 73. Minimum 5/6. Maximum 4/60. Average 40.

Anosia plexippus—

0·6 gramme per 300 c.c.

No. 7. Minimum 2/15. Maximum 2/66. Average 42.

1·5 grammes per 300 c.c.

No. 13. Minimum 3/20. Maximum 1/78. Average 44.

3·7 grammes per 300 c.c.

No. 70. Minimum 6/6. Maximum 4/63. Average 40.

Prodenia littoralis—

0·6 gramme per 300 c.c.

No. 10. Minimum 2/18. Maximum 2/90. Average 62.

1·5 grammes per 300 c.c.

No. 12. Minimum 1/6. Maximum 3/54. Average 36.

Ophiusa melicerte—

Half an ounce per gallon sprayed on castor plants—16 larvæ—2 died in 29 hours, 2 in 120, rest pupated.

Prior to the testing of dry paints, we regarded this as a very likely compound and we commend it to the notice of those who want an insoluble copper compound which is not really poisonous and is a good deterrent. A method of preparing it is given in Appendix IV; we believe that further work with this compound would prove it to be a very useful mild insecticide or deterrent.

COPPER SULPHIDE. Cu S.

Caradrina exigua :—

0·5 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
12	1/42	4/78	64
18	3/30	1/78	50

1·5 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
12	1/6	5/78	58
20	1/6	10/54	42
19	5/12	3/62	35·8
55	6/27	4/69	48

4·5 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
18	9/9	4/54	26
16	3/6	9/30	23
20	2/18	6/56	41

Prodenia littoralis—

0·5 gramme per 300 c.c.

No. 20. Minimum 4/24. Maximum 1/60. Average 36·7.

1·6 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
5	1/16	1/52	38
20	5/31	15/36	35

4·5 grammes per 300 c.c.

No. 20. Minimum 2/6. Maximum 1/78. Average 40.

Pierid—

0·5 gramme per 300 c.c.

No. 14. Minimum 1/44. Maximum 1/156. Average 91.

1·5 grammes per 300 c.c.

No. 13. Minimum 1/20. Maximum 1/156. Average 76.

4·5 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
19	10/22	2/58	28
20	12/14	1/63	27·4

Anosia plexippus—

1·6 grammes per 300 c.c.

No. 6. Minimum 2/18. Maximum 1/78. Average 49.

4·5 grammes per 300 c.c.

No. 4. Minimum 2/12. Maximum 2/36. Average 24.

Ophiusa melicerte—

In the open on castor, at ½ oz. per gallon, of 6 none died, of 10 2 died in 4 days, the rest survived and pupated.

In the open on castor, 1 oz. per gallon, of 10 none died, the leaves were eaten, they all pupated.

Copper sulphide is apparently of little value in small doses, a strength of somewhere near 1 lb. to 10 gallons very well applied being required to have any effect. It is a deterrent but as an insecticide,

good Bordeaux mixture would probably be far more effective and lasting. Its use as a powder deterrent is indicated.

BORAX. $Na_2 B_4 O_7$ $10 H_2 O$.

Caradrina exigua—

1·0 gramme per 300 c.c. No effect.

3·1 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
18	2/12	1/111	41
16	1/8	1/108	38
17	4/5	4/120	45
16	6/6	2/136	57

Prodenia littoralis—

3·1 grammes.

No. 9. Minimum 2/19. Maximum 1/79. Average 36.

Anosia plexippus—

3·1 grammes.

They died after 2 days or more, leaving the food practically untouched; 3 trials were made with 29 larvæ, but the results were the same in each.

No.	Minimum.	Maximum.	Average.
11	1/30	1/72	42
8	2/43	2/63	52
10	1/24	1/72	55

Sprayed on to castor plants, at ½ oz. per gallon, it had little effect—2 died in 24 hours, 1 in 120 hours, 17 pupated; at 1 oz. the figures were 6/72, 4/90, 1/96, 1/120 1/132, 2/156, 2/200 : 3 pupated.

Borax is of interest as being one of the very few compounds used as an insecticide for Blattids, which is neither an arsenical nor an alkaloid; a one per cent. solution is a fairly effective stomach poison and a good deterrent, but the Sodium salt cannot of course be used in general practice; and the insoluble borates have less action than this one, with the exception of the copper salt above mentioned.

Boracic Acid. $B(OH)_3$.

Prodenia littoralis—

2·1 grammes per 300 c.c.

No. 8. Minimum 6/30. Maximum 1/54. Average 35.

Caradrina exigua—

2·1 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
17	1/15	3/92	56
38	2/24	4/75	50

Anosia plexippus—

2·1 grammes per 300 c.c.

They totally declined food and died of starvation in from one to three days.

Boracic acid at this strength is clearly a deterrent and a poison of the second class. It cannot of course be used practically. Its poisoning action like that of borax may be due to the fact that insects feeding normally on leaves of whatever kind never meet with it and so are totally unused to it.

LEAD OXIDE. (RED LEAD). Pb_3O_4.

Caradrina exigua—

3·7 grammes per 300 c.c.

No. 50. Minimum 4/7. Maximum 6/66. Average 41.

Prodenia littoralis—

3·7 grammes per 300 c.c.

No. 9. Minimum 1/16. Maximum 1/76. Average 44.

Anosia plexippus—

No. 13. Minimum 3/24. Maximum 1/57. Average 36.

These figures are curiously uniform and clearly put Red lead in class 2, as a valuable insecticide; it is good for its other qualities as well, such as cheapness, availability, insolubility and the like.

LEAD SULPHIDE. Pb S.

Prodenia littoralis—

4·0 grammes per 300 c.c.

No.	Minimum.	Maximum.	Average.
4	1/36	2/60	51
4	1/48	1/90	69·5

Anosia plexippus—

No. 10. Minimum 2/16. Maximum 1/72. Average 37·8.

Caradrina exigua—

No.	Minimum.	Maximum.	Average.
13	1 36	1 150	77·5
15	4 30	1 54	40·
11	1 6	3 90	52·4
10	9 9	1 21	10·2
9	4 20	2 48	30·2

This compound appears to be similar in its effects to Lead oxide (Red lead). As the sulphide would have to be used in its precipitated form, the oxide would probably be cheaper and more convenient.

LEAD BORATE. $Pb\ B_4\ O_7$.

Caradrina exigua—

1·0 gramme per 300 c.c.

No.	Minimum.	Maximum.	Average.
4	1/78	1/94	84·5
12	1/42	1/96	76

It might have been expected that this compound would have proved at least as efficient as Lead oxide, if only because Boric acid gave such decidedly favourable results. The above figures for Lead borate are distinctly worse than those for either Boric Acid or for Lead oxide.

LEAD CARBONATE. $Pb\ Co_3$.

Caradrina exigua—

4·38 grammes per 300 c.c.

No. 12. Minimum 1/36. Maximum 1/126. Average 78.

See also "White Lead" page 285.

BARIUM PEROXIDE.

Caradrina exigua—

2·8 grammes per 300 c.c.

No effect. The larvæ (18) lived up to a week and then pupated.

BARIUM CARBONATE—

Caradrina exigua—

No effect.

The results contrast rather strongly with those obtained from Barium oxalate and Barium borate, *vide* below. The latter compounds, while variable in their effects, gave indications of a considerably higher killing power. It is probable that the latter is rather a measure of the respective powers of Boric and Oxalic acids than of that of Barium.

BARIUM OXALATE.

Caradrina exigua—

4·1 grammes per 300 c.c.

In the first trial with 4 caterpillars, the following results were obtained :—

1 died in 6 hours.	average killing power—40.
1 „ „ 12 „	
1 „ „ 72 „	

but in a subsequent trial with 12 caterpillars only 2 died in 3 days and the rest pupated.

It would appear therefore that the effect of Barium oxalate, while distinctly good in some cases, is not sufficiently constant to be depended on even at the great strength of 1 lb. in 7 gallons.

BARIUM BORATE. $B_a B_4 O_7$.

(*a*) At a strength of 0·6 gramme per 300 c.c. and 1 lb. in 50 gallons, this compound was without effect.

(*b*) At a strength of about 1 lb. in 10 gallons one experiment gave an average killing period of 35 hours and a second one of 50 hours. In a third experiment however, out of 15 caterpillars, only one had died in 36 hours when the experiment was stopped.

These results vary amongst themselves to such an extent as to render further trials advisable ; but judging from the figures for other compounds of Barium, it is not probable that Barium borate would, at reasonable strength, prove to have a powerful insecticidal effect.

ZINC OXIDE. $Zn O$.

Caradrina exigua—

1·3 grammes per 300 c.c.

The mean of six experiments at the above strength with this compound gave an average killing power of 52 with extremes of 84 and 27.

While the extreme figures would place Zinc oxide low in the scale of possible insecticides, the low figures, of which there were two below 40, make it, on account of its cheapness, well worth further investigation.

Zinc sulphide. 1·5 grms. per 300 c.c. ZnS.—

At the above strength Zinc sulphide was quite ineffective with (*a*) larvæ of *C. exigua*, (*b*) Pierid caterpillar on Bagnai.

OXIDE OF IRON. (1 lb. in 16 gallons).

Diacrisia obliqua—

The following are the results with this compound :—

20. 1/96 4/120 2/144·13 pupated. Average 1·123.

All the food given to the caterpillars was eaten, and Oxide of iron is obviously quite harmless.

BURNT SIENNA—

See results on p. 285.

BURNT UMBER—

See results on p. 285.

PRUSSIAN BLUE—

See results on p. 285.

YELLOW OCHRE—

See results on p. 285.

ULTRAMARINE BLUE—

See results on p. 285.

LEMON CHROME—

See results on p. 285.

CHROME ALUM—5·5 grammes in 300 c.c.

(*a*) Pierid caterpillar on *Copparis*.

(*b*) Larvæ of *Caradrina exigua*.

This compound proved to be harmless as no deaths took place within 5 days.

ALUM—5·0 grammes in 300 c.c.

Pierid caterpillar on *Copparis.*

At the above strength, the killing power of this compound was only 115. It is therefore useless.

MAGNESIUM OXIDE—

Had no effect at all.

MAGNESIUM CARBONATE—

No effect.

MAGNESIUM SULPHATE. 4·1 grammes in 300 c.c.

(*a*) *Caradrina exigua*—

This compound appears to have a much more powerful effect than either the Oxide or the Carbonate, for out of 20 caterpillars 11 died in an average of 45 hours. Even on this result however Magnesium sulphate would only come into class III. Its solubility, of course, would prevent its being used in practice; but it might be worth while trying the effect of a Magnesium borate or of Magnesium oxalate.

(*b*) *Sylepta.* No effect.

STANNOUS CHLORIDE. 3·1 grammes per 300 c.c.

Caradrina exigua—

Three died in 36 hours, two in 60, the rest (12) were unaffected.

Sylepta derogata—

No effect.

SODIUM CARBONATE. 4·4 grammes per 300 c.c.

Caradrina exigua—

The average killing power, in one experiment, of this compound was, 51; probably due to its caustic properties. The latter however as well as its solubility prevent its being considered as a practical insecticide, even if its killing power was sufficiently great.

POTASSIUM CHLORIDE. K Cl. 2·5 grammes per 300 c.c.

(*a*) *Caradrina exigua*—

With this compound, in one experiment—

3 caterpillars died in 24 hours.
4 more " " 30 "
1 " " " 54 "

Its average killing power was therefore 37 ; a fairly good result ; but the compound is not, on account of its solubility, a possible insecticide.

Sylepta derogata—

No effect.

COPPER TANNATE—

2 grammes of $Cu\,S\,O_4.5\,H_2\,O$ in 300 c.c.
4 " " Tannic Acid " " "

Prodenia littoralis—

No. 20. Minimum 1/48. Maximum 5/144. Average 112.

It is interesting to compare this with Lead Tannate, which is distinctly class IV. One would not perhaps expect Tannates or Tannic Acid at all to affect insects and the action may be due solely to the metallic salt.

LEAD TANNATE. 7 grammes in 300 c.c.

4 grammes Lead Acetate.
3 " Tannic Acid.

Prodenia littoralis—

This compound was found to be incapable of killing more than 8 out of 20 caterpillars in 5 days. It is therefore much less powerful than Copper Tannate. The figures were—

20 larvæ.
2 died in 96 hours.
1 " " 100 "
1 " " 108 "
1 " " 120 "
3 " " 144 "
6 pupated.
2 more pupated.
4 failed to pupate.
6 moths emerged.
2 " failed to emerge.

MANGANESE DIOXIDE. $Mn O_2$.

No result.

IRON SULPHIDE. Fe S.

No result.

PHENYL HYDRAZINE HYDROCHLORIDE. 1·8 grammes in 300 c.c.

Caradrina exigua—

No. 20. 2/30, 6/60, 12 unaffected.

Sylepta derogata—

No. 20. Minimum 1/6. Maximum 7/48. Average 27·3.

Diacrisia obliqua—

No. 10. Minimum 2/85. Maximum 1/240. Average 140.

ACETAMIDE. 2·0 grammes in 300 c.c.

Caradrina exigua—

20. Minimum 1/30. Maximum 6/60. Average 55. 10 caterpillars left unkilled.

METAPHENYLENE DIAMINE HYDROCHLORIDE. 2·4 grammes in 300 c.c.

Caradrina exigua—

No. 20. 3/30, 2/54, 2/60. 11 unaffected.

This compound had no effect on the Cotton leaf-roller.

POTASSIUM FERROCYANIDE. 2·0 grammes in 300 c.c.

Sylepta derogata—

No effect.

Caradrina exigua—

No. 20. 1/24, 3/36, 6/60, 9 left.

It appears from this and from results obtained for other compounds that *C. exigua* is much more easily affected than the Cotton leaf-roller.

POTASSIUM FERRICYANIDE. 1·8 grammes in 300 c.c.

Sylepta derogata—

No effect.

Caradrina exigua—

No. 20. 2/36, 5/60, 12 left.

This result corresponds very closely with that for Potassium ferrocyanide. Neither is sufficiently good to render it an efficient insecticide, even if its solubility were not a bar to its use.

PICRIC ACID. 2·5 grammes in 300 c.c.

Sylepta derogata—

No effect.

Caradina exigua—

No. 20. 1/24, 3/36, 5/60, 10 left.

POTASSIUM BICHROMATE. 1·6 grammes in 300 c.c.

Sylepta derogata—

No effect.

Caradrina exigua—

No. 20. 3/36, 5/60, 2 parasitised, 10 left.

Morphine. 0·3 grammes in 300 c.c.

At the above strength, no appreciable effect was produced in *Sylepta derogata*.

AMMONIUM PERSULPHATE. 1·0 grammes in 300 c.c.

Sylepta derogata—

With very large specimens in one experiment no effect was produced. In a second trial with smaller caterpillars the following results were obtained :—

20—1/6, 6/36, 5/60, 1/72, 2/84 = 50.

Caradrina exigua—

1st trial :—20—13/12, 2/22, 1/24, 2/36, 1/52, 1/96 = 22.

2nd trial :—20—1/6, 2/30, 7/54, 9 left.

Judging by its effect both on *Sylepta* and *Caradrina*, Ammonium persulphate is a fairly powerful insecticide and it would appear that the effect of insoluble compounds of this acid might be worth investigating.

Sodium benzoate. 4·8 grammes in 300 c.c.

No appreciable effect on either the Pierid caterpillar or on *Caradrina exigua*.

CAFFEIN. 0·3 gramme in 300 c.c.

Caffein was found to be quite ineffective with *Sylepta.*

Sodium tartrate. 3·8 grammes in 300 c.c.

No action on Pierid caterpillar or on *C. exigua.*

TARTARIC ACID. 2·5 grammes in 300 c.c.

No action on *C. exigua.*

SULPHUR. 0·5 gramme in 300 c.c.

No action on Pierid caterpillar or on *C. exigua.*

QUININE. 5 grammes in 300 c.c.

No appreciable action on the Pierid caterpillar or on *Caradrina exigua.*

CARBOLIC ACID. 3·0 grammes in 300 c.c.

Had no effect on Pierid caterpillar or on *C. exigua.*

SODIUM SUCCINATE. 2·8 grammes in 300 c.c.

No appreciable effect on Pierid caterpillar.

TANNIC ACID. 3·0 grammes in 300 c.c.

No effect on Pierid caterpillar.

GALLIC ACID.

No effect.

LAC. 4·0 grammes in 300 c.c.

Sylepta derogata—

20—5/7, 4/38, 8/14, 1/24, 2/26 = 18·75.

Diacrisia obliqua—

10—2/78, 2/126, 2/174, 1/198 = 136.

Lac thus proved to have a powerful killing effect on *Sylepta derogata* which is particularly resistant to many other inordinate poisons.

In the case of *Diacrisia obliqua,* its actual killing power is very low according to the figures; but for 3 whole days, the caterpillars refused to eat the lac-treated leaves; lac, in this case, appears to have acted as a very effective preventive.

On the whole it would appear that lac has sufficient possibilities as a preventive to justify further trials.

CHLORAL HYDRATE. 2·75 grammes in 300 c.c.

Sylepta derogata—

Practically no effect.

Caradrina exigua—

(1) 20—11/13, 1/23, 1/24, 2/36, 2/60, 2/70, 1/147 = 34.

(2)—20. None died in 48 hours.

The above results do not indicate that this substance has any probable value.

STRYCHNINE. 0·3 gramme in 300 c.c.

Caradrina exigua—

14—4/18, 3/30, 2/54, 5/78 = 46.

Pierid caterpillar—

(1) 20—1/6, 11/15, 1/24, 7/31 = 21.

(2) 19—2/5, 4/8, 9/38, 3/50, 1/56 = 31.

Sylepta derogata—

10—3/12, 1/24, 3/36 = 16·8.

In this case 20 caterpillars were put into the cage but the experiment was stopped after 48 hours.

The general effect of the small amount of Strychnine used, 1 lb. in 100 gallons, shows that its effect is a powerful one. In the case of the Pierid caterpillars the whole number put in were moribund in 8 hours. The price of pure Strychnine would be prohibitive: but it is possible that a crude preparation might be sufficiently cheap to allow of its being used economically.

BRUCINE. 0·3 gramme in 300 c.c.

Sylepta derogata—

(1) 14—2/24, 4/60, 3/72, 5/84 = 66.

(2) 20. None died in 48 hours although leaves were eaten. Brucine is therefore far less powerful in its action than Strychnine.

SACCHARIN. 2·0 grammes in 300 c.c.

Sylepta derogata—

17—2/12, 1/56 = 58·7

6/14, 2/38, 2/86, 1/132 = 1/180.

It is obvious from the above figures that Saccharin does not offer any possibilities of useful application.

POTASSIUM IODIDE. 5·5 grammes in 300 c.c.

(*a*) *Cotton Leaf-roller*—

No effect.

(*b*) *Caradrina exigua*—

26—2/24, 3/36, 3/60. 13 left.

(*c*) *Sylepta derogata*—

No effect.

Potassium Iodide has therefore no marked action.

PART III.

The series of experiments above described are all on captive insects fed on picked food, not on the growing plant or free to wander. What actually happens in field spraying? Do the caterpillars feed and die, do they feed, get ill and wander away or what happens? From observation of sprayed crops, we believe that both the above occur, but that with some poisons death occurs fairly soon as the insects do not perceive the poison, in others the poison is either tasted or makes them unwell and they then wander, seeking unsprayed food and are gradually poisoned, are starved or are destroyed by birds since they wander off the plants. This can be well illustrated by feeding caterpillars on plants growing in the open under cages. In one instance, *Diacrisia* were feeding on the wild nettle; a clump was sprayed with Lead Chromate in water and a cage put over, large larvæ of *Diacrisia* were then put in; they fed a little here and there but not normally; they wandered about the cage; they remained alive for several days and actually managed to eat into the succulent stems and feed on the unsprayed tissue; they became boring larvæ to some extent, a habit they never show normally and but for being incommoded by their dense covering of hairs they would possibly have gone completely inside. This illustrates very well the deterrent action of Lead Chromate and this action is not confined to this compound. The action of Naphthalin is discussed below in Appendix III.

It would appear that one can think of stomach poisons in two ways; there are those which are unperceived poisons, the insect absorbing a lethal dose before the effects manifest themselves (either on account of the virulence of the poison or of its not producing irritant symptoms); there are those which are less poisonous but which either produce irritant symptoms or are perceived, rendering the food-plant distasteful. Which action an individual

compound has, depends to some extent on the caterpillar used, but if one tests compounds on one caterpillar throughout, one sees very marked differences in the way the poisoned food is taken. On the other hand different kinds of caterpillars shew marked difference in resistant power to the same poison.

Speaking generally the most marked "deterrent" action was that of Lead Chromate; perhaps the least was the Lead Arseniate itself but all in class I come under the category of poisons and not of deterrents. The classes into which we divide our compounds are therefore not based wholly upon actual poisoning effects: a marked deterrent action slows the action of the poison very much, giving it a higher lethal figure; in practice therefore we have to select from classes I & II together.

The practical outcome of all these experiments has been the selection of Lead Chromate as a standard stomach poison to replace arsenical poisons; and the selection of certain available dry paints which are recommended for application as deterrents on young crops. An article describing the use of Lead Chromate as an insecticide was published in the Agricultural Journal of India (Vol. V. p. 138). An extract from this is appended (Appendix II). Its use has also been described in Bulletin No. 23, Agric. Res. Inst., Pusa, on insecticides. It is available as a powder, pure or at strengths of 33% or 50%, and as a paste containing 66% of Lead Chromate. It may also be prepared from Potassium Bichromate and Lead Nitrate or Lead Acetate.

The further outcome has been the use of "dry paints" as deterrents particularly on young crops; the following are available in India at the approximate indicated prices:

Lead Chromate ..	Lemon Chrome	As. 6 to 12 as. per lb.
Lead Oxide ..	Red Lead	Rs. 23 per cwt.
Lead Carbonate ..	White Lead	„ 24 „
Iron Oxides ..	Oxide of Iron	„ 14 „
„ „ ..	Yellow Ochre	„ 14 „
„ „ ..	Red Ochre	„ 14 „
„ „ ..	Burnt Sienna	As. 12 lb.
Iron and Manganese	Burnt Amber	„ 7 „
Zinc and Cobalt Sulphide.	Saxon Green	„ 6 „

These are used for dusting particularly on young crops, such as cereals, tobacco, cotton, etc., which are attacked by grasshoppers and surface weevils.

The experiments have also brought out the value, as a stomach poison, of Naphthaline Emulsion. The great advantage is its volatility, so that green plants intended for consumption can be safely sprayed when mature. Its preparation is dealt with in Appendix III.

Although the experiments now described have been very numerous, the work can only be regarded as a more or less rough preliminary to a much more thorough investigation of individual compounds which have given indications of possible utility. In addition to those already mentioned in this summary, we would draw attention to the following:—

Lead Oxide.
Lead Sulphide.
Copper Oxide.
Copper Sulphide.
Borates.
Oxalates.
Phenyl Hydrazine Compounds.
Barium Compounds.
Lac.
Zinc Oxide.

APPENDIX I.

The insects used as subjects in this investigation are the following:—

Caradrina exigua, Hübn. A common caterpillar, with a large range of foodplants, feeding on indigo, lucerne, maize, cotton, safflower, gram, and a number of weeds. A full account of it has been published. (Agricultural Journal of India, Vol. I, p. 338 [1906]).

Prodenia littoralis, Boisd. Another common caterpillar, with a still larger range of foodplants, including tobacco, indigo, lucerne, cabbage, castor, jute, potato, mulberry, etc. A full account of it has been published. (Memoirs of the Department of Agriculture in India, Entomological Series, Vol. II, No. 5 [1908]).

Ophiusa melicerte, Dr. The semi-looping caterpillar of the castor plant, known to feed also on *Euphorbia pilulifera*. A full account has been published. (Memoirs of the Department of Agriculture in India, Entomological Series, Vol. II, No. 4 [1908]).

Anapheis mesentina, Cram. Referred to as the "Pierid." A common caterpillar feeding upon *Capparis horrida* (Bagnai).

Marasmia trapezalis, Guen. The Maize Leaf-roller. A Pyralid common on maize.

Diacrisia obliqua, Wlk. The Behar Hairy Caterpillar: an Arctiid which is extremely omnivorous and abundant.

Sylepta derogata, Fabr. The Cotton Leaf-roller. It has a range of foodplants in the *Malvaceæ* chiefly. A full account has been published. (Memoirs of the Department of Agriculture in India, Entomological Series, Vol. II, No. 6 [1908]).

Anosia (Danais) chrysippus, Linn. Feeds on *Calotropis* spp.

Cosmophila sabulifera, Wlk. The Jute Semi-looper. An account

has been published. (Agricultural Journal of India, Vol. II, p. 109 [1907]).

Acridium aeruginosum, Burm. (*Cyrtacanthacris ranacea*, Stoll.). The Black Spotted Grasshopper. Feeds on cotton. (Indian Insect Life, p. 86).

APPENDIX II.

Having defined classes I and II, the practical necessities of the case were considered; for instance, Iodoform is very deadly, but useless as a field insecticide. We therefore turned to the substances in classes I and II that might be useful, and we found that some of them might be commercially available. What are the conditions which an insecticide must fulfil? It must be (*a*) insoluble in water or rain washes it off; (*b*) cheap and easily available; (*c*) stable and not apt to decompose into compounds that poison the leaf.

Eliminating from classes I and II the compounds not fulfilling these conditions, there remained a small number of substances, not of very high killing value, that might be valuable as "deterrents" if not as "insecticides." Thus, a plant sprayed with Copper Sulphide might be so distasteful to caterpillars that they would leave it even if it did not poison them. The commercial possibilities of these were investigated, and it was found some of them were available as dry paints; these were tested, and among them was a particularly effective compound sold as Lemon Chrome; this consists of Gypsum and Lead Chromate in particular proportions to give a lemon yellow tint. Lead Chromate was accordingly tested and gave good results; its poisoning action was high, and it seemed likely to be a commercial possibility. Up to now all the tests were insectary ones; field tests were then made, first on plants under control with a definite number of caterpillars on; then, as opportunity offered, on crops attacked by caterpillars. On these field tests, it was found that some otherwise suitable compounds injured the plants, and as a result of these tests, all other compounds but Lead Chromate were, for the present, abandoned. Lead Chromate offers distinct advantages; it is easily made in paste form; it is yellow and can be easily seen on a sprayed plant; it is extremely insoluble; soluble chromates

do not poison plants to the extent arsenic does, so even were it to decompose, it would not be injurious; it does not decompose on a leaf; it is not easily washed off; it contains no arsenic. During this year we have applied this compound to a great variety of crops; we have sprayed them till every leaf was yellow; the poison has remained on for over three weeks, thickly on the leaves, which were uninjured; sprayed on to crops attacked by caterpillars, the caterpillars are killed, and the results obtained have been excellent. We have used this at 1 lb. in 32 gallons; at this strength it is entirely safe, poisons caterpillars and acts as a very powerful deterrent.

In protecting plants from caterpillars and grasshoppers there are two things to consider: are you dealing with a caterpillar which feeds specially on that plant, or are you dealing with a grasshopper or beetle which is not restricted to that plant? For the former you must apply an insecticide, a real killing agent, that will poison it, because it can feed on nothing but that plant, and all its instincts are to do so; for the latter, a deterrent is sufficient, because it will leave that sprayed crop and go elsewhere. In certain cases a deterrent is sufficient; in others, especially with caterpillars, you must apply a really deadly compound in small amounts that will actually kill. Lead Chromate has not the poisoning effect of Paris Green for instance, which can be applied at one pound in 200 gallons: but it has a poisoning effect comparable with that of Lead Arseniate and is, in our experience, a perfect substitute.

Lead Chromate is made by dissolving in one lot of water Potassium Bichromate, in another lot of water Lead Acetate or Nitrate. The two solutions are mixed, and a dense yellow precipitate of insoluble Lead Chromate is formed, and Potassium Nitrate or Acetate. The latter is soluble and is readily washed out of the precipitate. We have neglected it and prepared our Lead Chromate by dissolving the Lead Salt in the spraying machine, dissolving separately the Bichromate and adding the solution to the spraying machine. The figures are as follows:—

66·2 grammes of Lead Nitrate combined with 29·4 grammes of Potassium Bichromate giving 64·6 grammes of Lead Chromate

allowing for impurities, we found that 65·2 grammes of commercial Lead Nitrate combined with 30 grammes of Potassium Bichromate; in practice 2 ounces of Lead Nitrate combined with one ounce of Potassium Bichromate giving two ounces of Lead Chromate: this is the actual amount required for one kerosene tin of water (4 gallons) at full strength or for two kerosene tins of water at the usual strength.

This is the best way to apply it, to mix the two solutions in the spraying machine and then apply it; but the paste can be purchased and arrangements have been made for the sale of this insecticide.

In India, there is a very large field for the use of insecticides, but they are as yet very little known. For many reasons they cannot be applied at present to ordinary field crops; but from experiment farms, from those cultivating valuable crops, fruit trees, or vegetables we get a steady stream of enquiries as to how to check beetles, grasshoppers, caterpillars and similar biting insects. To all these there is but one answer: apply a stomach poison; now that a non-arsenical stomach poison is available, and that a thoroughly good reliable hand sprayer can be bought at a reasonable price in India, there is no reason why such pests should not be dealt with. At Pusa we have occasion to use stomach poisons constantly; against all insects that injure crops by biting the leaves, we use Lead Chromate and we can use no other method that is equally effective and cheap. The discovery of a substitute for arsenic removes one objection to this method of treatment, and we believe that there is no reason why the use of this insecticide should not entirely remove the losses experienced from this class of pest on the more valuable crops and on experiment farms. There is at present no commercial agency that advertises and pushes the sale of insecticides and machines, but we have arranged for the sale of this insecticide and will give particulars on application. (Agricultural Journal of India, Vol. V, p. 138, "A New Insecticide.")

APPENDIX III.

PREPARATION OF NAPHTHALENE EMULSION.

"Dissolve 6 oz. size (Patna sirish) in ½ gallon water; into this stir 1 lb. of soft soap. Dissolve 1 lb. of naphthalene in 1 gallon of kerosene. Mix the two solutions at once, and add another half gallon of water. The size-soap solution must be as hot as possible and the mixture must be well agitated while mixing."

In actual practice, we tried varying amounts of naphthalene; as this is the active ingredient, it is desirable to have as much of it as possible; by warming the oil, more naphthalene is dissolved and it was found that the emulsion came successfully in every case. Two, four, six and eight pounds of naphthalene were dissolved in the kerosene by warming for 6 lbs. the oil was heated to 123°F. (43°C.), for 8 lbs. to 140°F. (58°C.); the temperature required for 8 pounds is as high as is safe in actual practice with ordinary heating over hot water or a fire.

Using 7 lbs. of Naphthalene the cost is :—

6 oz. Size	2 as.
1 lb. Soft Soap	2 „
1 gallon Kerosene	14 „
7 lbs. Naphthalene	16 „
Rs. ..	2-2-0.

Using this at 5 lbs. of Naphthalene to 100 gallons makes the cost per 100 gallons about Re. 1-14-0.

At this strength, the mixture was tested on Castor for *Ophiusa melicerte*, and *Prodenia littoralis*, half the field being sprayed with Lead Arseniate at the same strength as a check. The concentrated

emulsion of Naphthalene mixes well with water, no separation taking place; it keeps well and there was no difficulty in application. The action was very curious: the plants were swarming with the caterpillars and were well sprayed with Knapsack sprayers. The immediate effect of the Napthalene was to make the caterpillars restless: they moved about seeking unsprayed leaves: they bored into the soft stems; the young ones died, the mature ones became sick: for one day all feeding practically ceased and the caterpillars were all moving; but next day, after a day of hot sunshine (temperature in the shade 95°F.), the plants were free of naphthalene: the caterpillers still in the field were feeding again; there was no smell of naphthalene and the destruction recommenced.

The half sprayed with Lead Arseniate gradually became clear of caterpillars; they died largely, though some moved away, but on the whole the action seemed to be one of direct poisoning. In three days it was clear and remained clear. The field was sprayed throughout at the same time and there was no space between the two halves.

Naphthalene applied in this way has no poisoning effect on any but small caterpillars; it has a deterrent effect and it is as a harmless deterrent, which will have evaporated in a day or two days that it is valuable as an insecticide. It is used on vegetable crops intended for consumption with great effect and it is useless as a field insecticide.

APPENDIX IV.

Preparation of Copper Borate on a large scale for field use.

As the composition of Copper Borate is stated to be uncertain and no really definite information could be found concerning it: a few experiments were performed to see if the preparation of Copper Borate by double decomposition from Copper Sulphate and Sodium Borate follow the equation :—

$$Cu\,So_4 . 5\,Aq + Na_2\,B_4\,O_7 \cdot 10Aq = Cu\,B_4\,O_7 + Na_2\,So_4 + 15Aq.$$

Solutions of Copper Sulphate (5%) and Borax (3·852 grammes per 100 c.c.) were made up, and portions of the one added to the other until no further precipitation took place and Potassium Ferrocyanide did not show its well-known reaction with Copper (a brown colouration) with a drop of the solution.

The reaction between the Borax and Copper Sulphate was found to be unsatisfactory: if the Copper solution be added to the Borax solution, constant results are obtained, but different though equally constant results are obtained if the Borax solution is added to the Copper solution. Thus when Copper was added to the borax, it was found that 1 c.c. of Borax solution was equivalent to 0·58 c.c. Copper solution, while when the Borax solution was added to the Copper solution it was found that 1 c.c. of Borax solution was equivalent to 0·68 c.c. of Copper sulphate solution.

As it is advisable to have the borax solution in slight excess, or in other words to precipitate all the copper it was decided to take

the first named figure, *i.e.*, 1 c.c. of Borax solution 0·58 c.c. of $CuSo_4$ solution. From this :—

0·03852 gramme Borax = 0·020 gramme $CuSo_4$.

or, roughly :—

4 of Borax = 3 of $CuSo_4$.

Preparation of the Spraying mixture.

From 6 parts of Borax and 5 parts of Copper Sulphate
4½ parts of Copper Borate are obtained.
You want 0·5 %, *i.e.*, 1 lb. in 20 gallons.
·2 „ „ 4 „
·38 lbs. of Borax and ·25 of $CuSo_4$ = ·2 of Copper Borate.
6 oz. „ „ „ 4 oz. „ = ·3 „ „ „
or one charge of the 4-gallon machine.

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